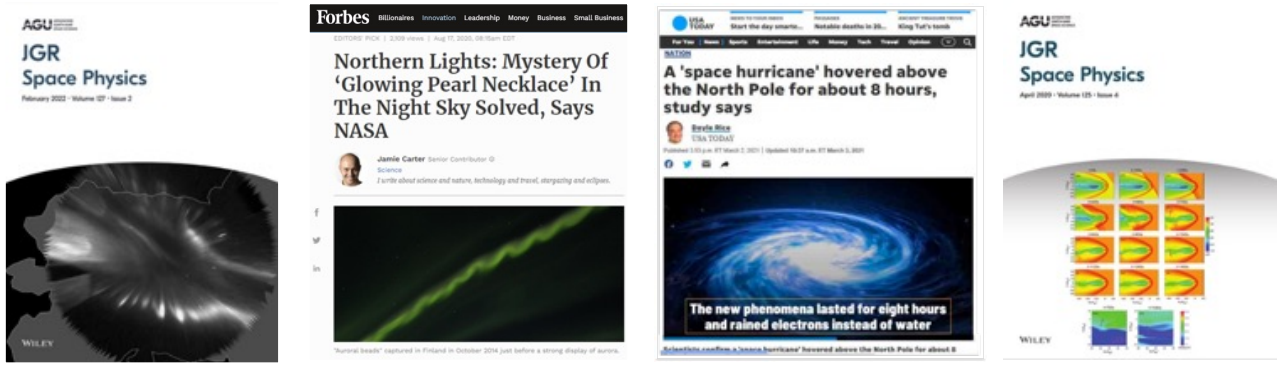
THEMIS/ARTEMIS: Still address timely, key HPS questions and are key to HSO

Ph-A started: 2002; Ph-B: 2003; Launched: 2007; ARTEMIS started: 2009 (Extended Phase); ARTEMIS at Lunar Lagrange orbit: 2010; Lunar Orbit Insertion: 2011; Pubs (total) >1950

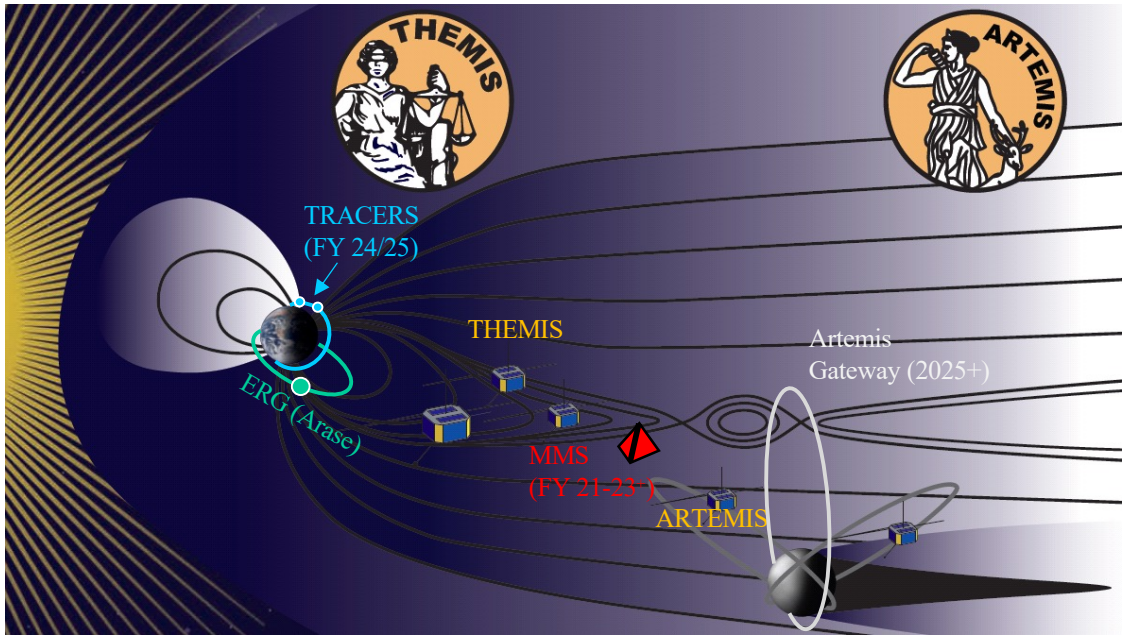
Since last Senior Review (2020):

- >140 refereed pub's/year
- 10 Nature group pub's
- 5 AGU Journal Covers
- 7 Press Releases
- Utilizing unprecedented conjunctions with MMS
- Addressed key questions on energy conversion at the tail-dipole transition region and at the dayside



In next 5 years:

- Hardware still in great shape!!
- Embarked on new objectives to unravel the drivers of storms & relativistic electron enhancements during emerging solar cycle 25.
- To remain a cornerstone of HSO
  - Synergy w/ other GBOs, MMS, Arase, TRACERS, HERMES and future SMEXes!



Was it smooth sailing? What were the main issues – and how were they avoided?

5th MIDEX: Time History of Events and Macroscale Interactions during Substorms (THEMIS)

Science Team

NASA Funded		Non-NASA funded	
UCB	V. Angelopoulos	TUBS	*U. Auster*
	C. W. Carlson‡		K.-H. Glassmeier
	G. T. Delory	IWF	W. Baumjohann
	R. P. Lin		R. Nakamura
	S. Mende		*K. Schwingenschuh*
	F. S. Mozer	MPAe	J. Buechner
	G. Parks	CETP	O. Le Contel
	T. D. Phan		*A. Roux*
	M. A. Temerin	UC	E. Donovan
UCLA	K. K. Khurana	ESTEC	*P. Escoubet*
	M. G. Kivelson		H. Laakso
	J. Raeder	TITech	M. Fujimoto
	C. T. Russell	CESR	C. J. Jacquey
CU	*R. E. Ergun*		D. LeQueau
	X. Li	UA	J. Samson
APL	A. T. Y. Lui		I. Voronkov
GSFC	D. Sibeck	USP	V. Sergeev
		NOAA	H. J. Singer

‡*Members responsible for hardware delivery are italicized*

RESOLVING THE PHYSICS OF ONSET AND EVOLUTION OF SUBSTORMS

Principal Investigator
Vassilis Angelopoulos, UCB

EPO Lead
Nahide Craig, UCB

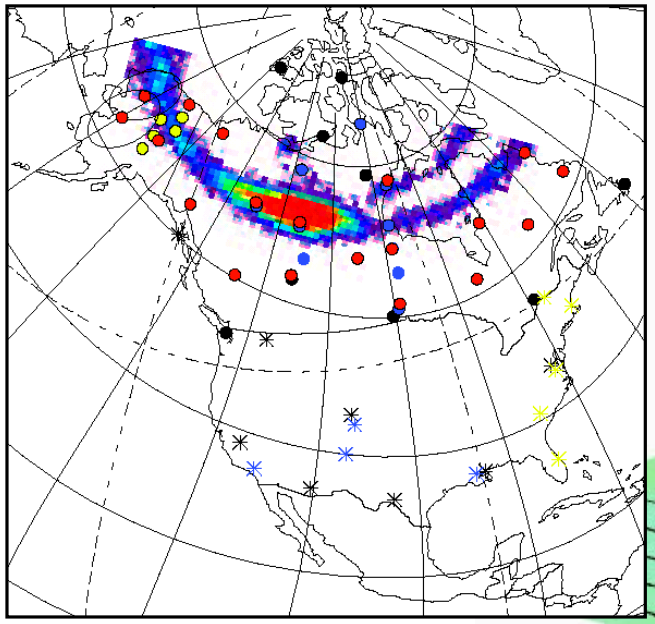
Program Manager
Peter Harvey, UCB

Industrial Partner
SWALES Aerospace, Inc., Beltsville MD

Mission Elements: 5 satellites (probes) and 20 ground-based observatories (GBOs)

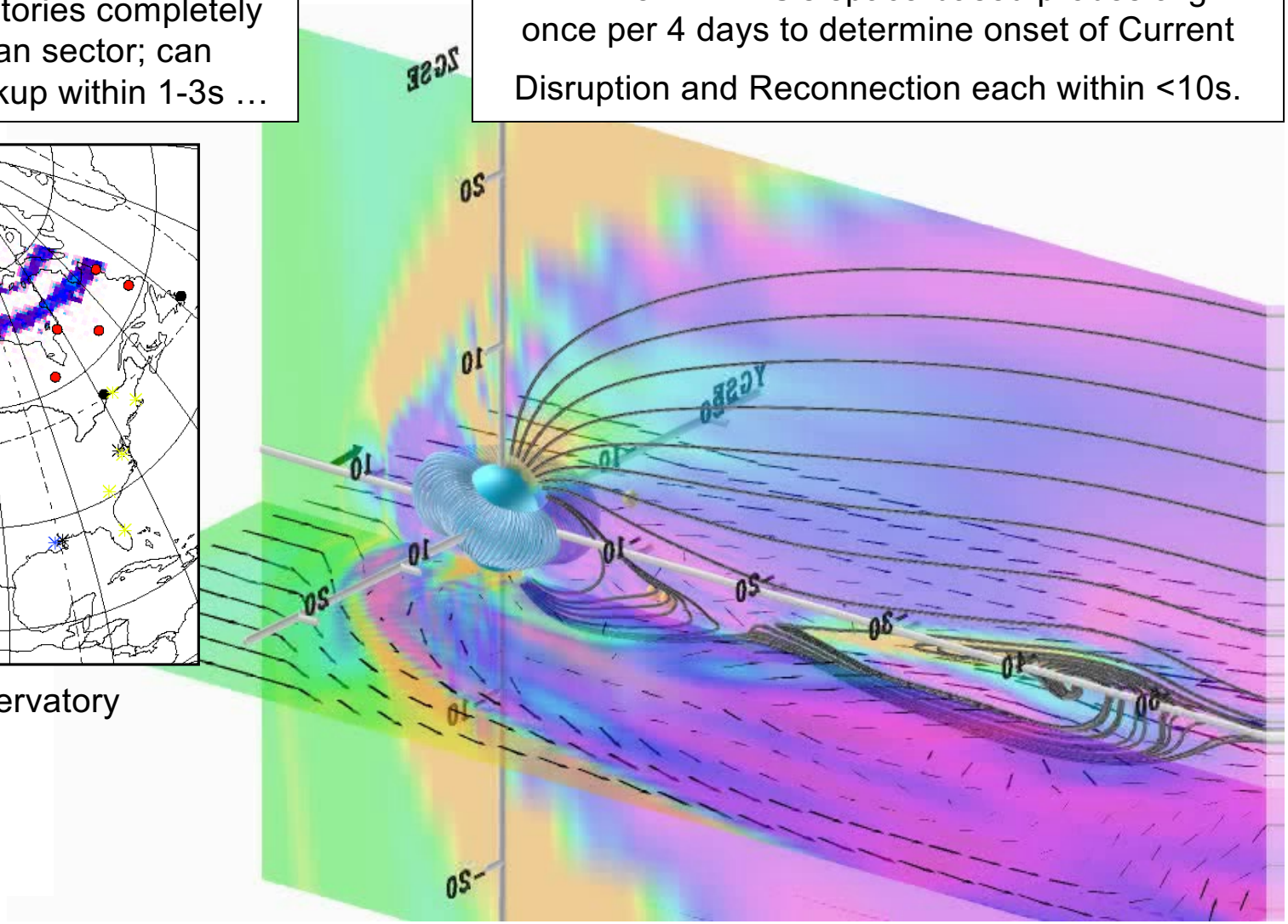
Probe conjunctions along Sun-Earth line recur once per 4 days over North America.

Ground based observatories completely cover North American sector; can determine auroral breakup within 1-3s …



●: Ground Based Observatory

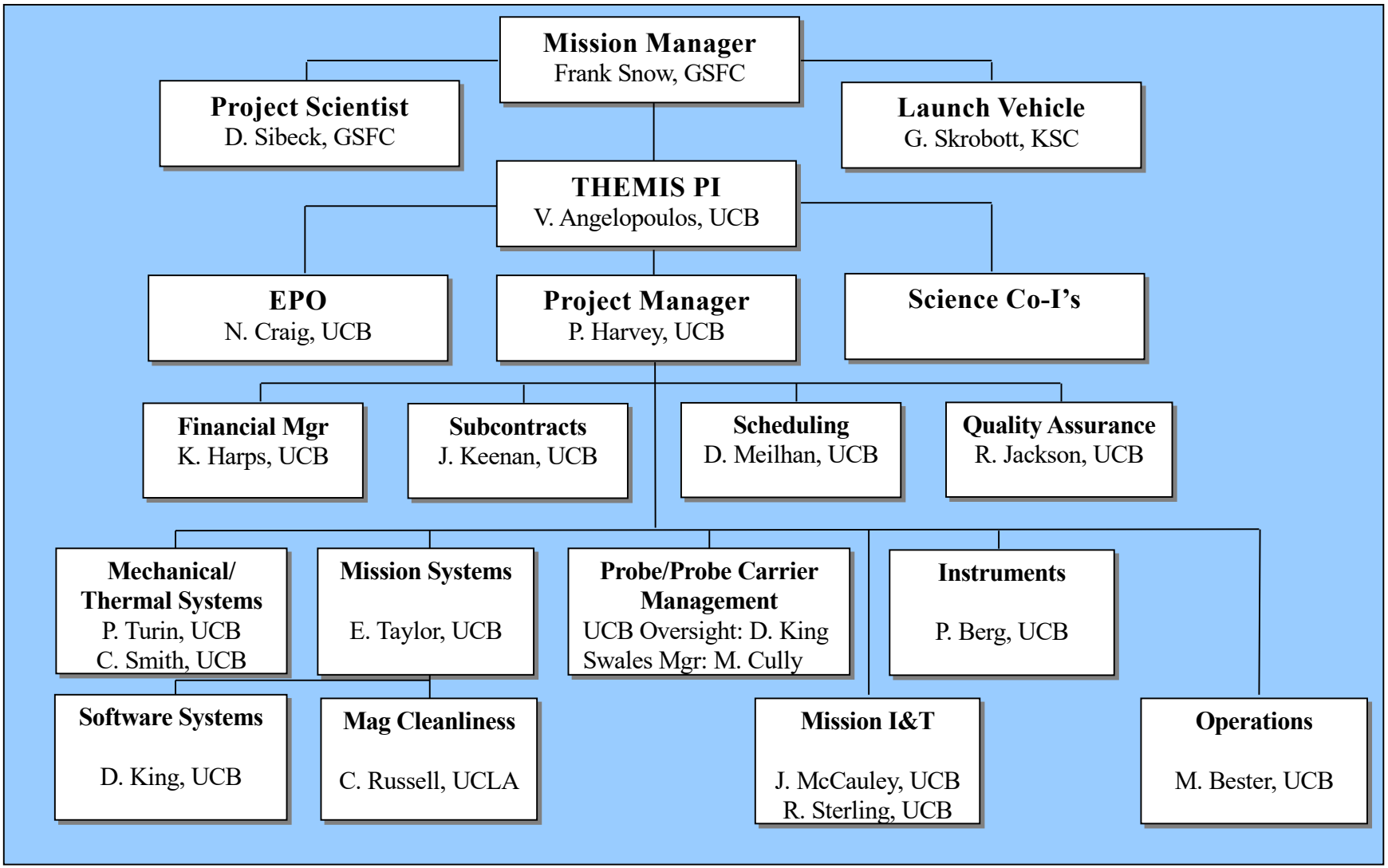
… while THEMIS's space-based probes align once per 4 days to determine onset of Current Disruption and Reconnection each within <10s.



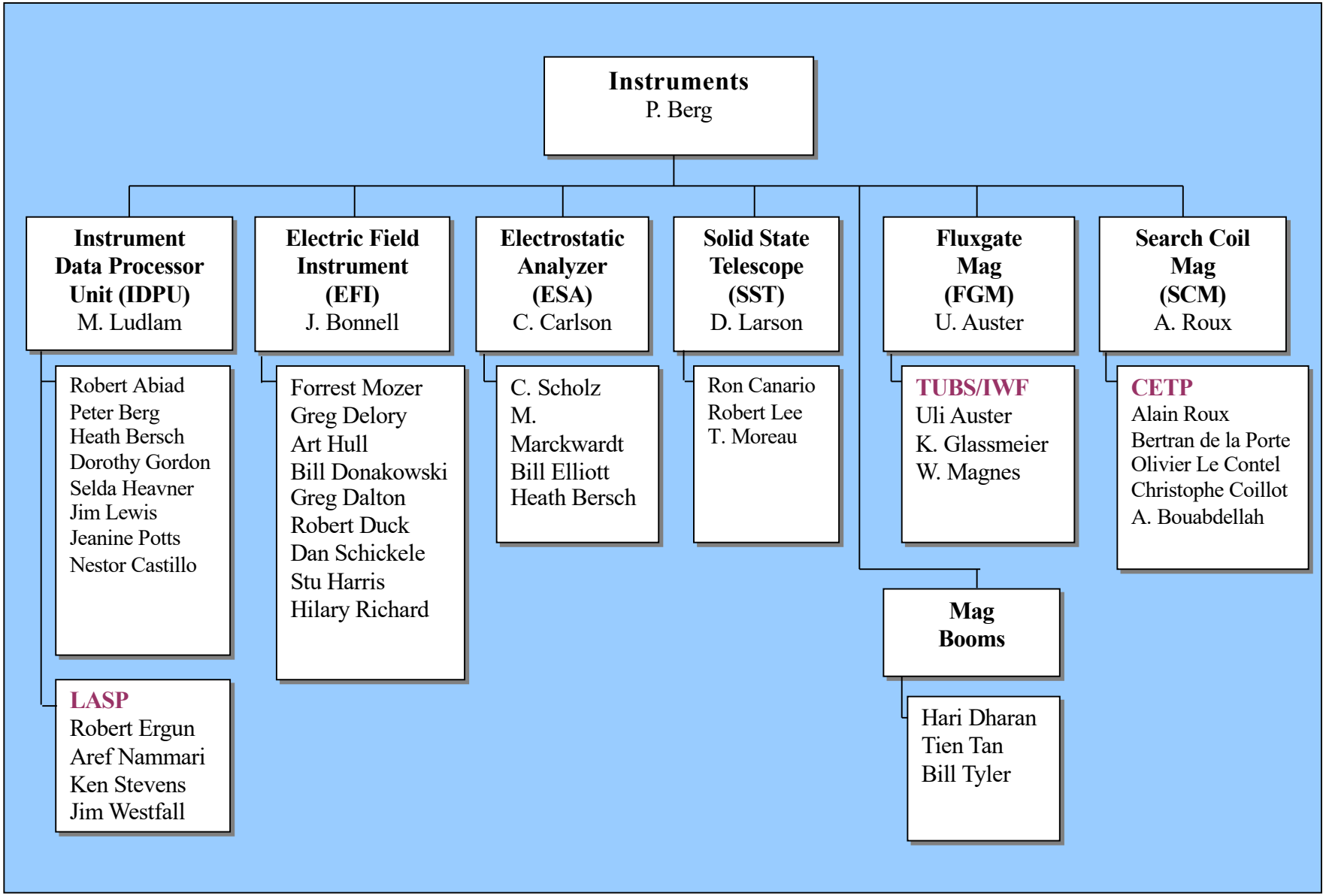
Program Organization and Outcome

- PI Mode
  - PI Team Provides Space, Ground, Data Segments
  - PI Team Provides Cost, Schedule, Performance Assurance
  - PI Team Provides Education/Public Outreach
- Cost and Schedule Caps
  - Single Cost Cap for the Mission $180M (FY07)
  - Launch no later than March 2007 (Launch was Feb 2007)
- Performance Assurance
  - MIDEX Quality Requirements (Grade 3 parts with selective upgrades; INST-001; Reliability analysis per MIL-STD 1629).
- ➢ Implementation Strategy
  - Use Heritage Instrumentation
  - Coordinate Common Buy Parts Program
  - Keep Probe/Probe Carrier Simple and Robust
  - Leave Complexity on the Ground
  - Build & Verify Probe 1, then Probes 2-5
- Result: On-time, on-budget delivery to a successful launch

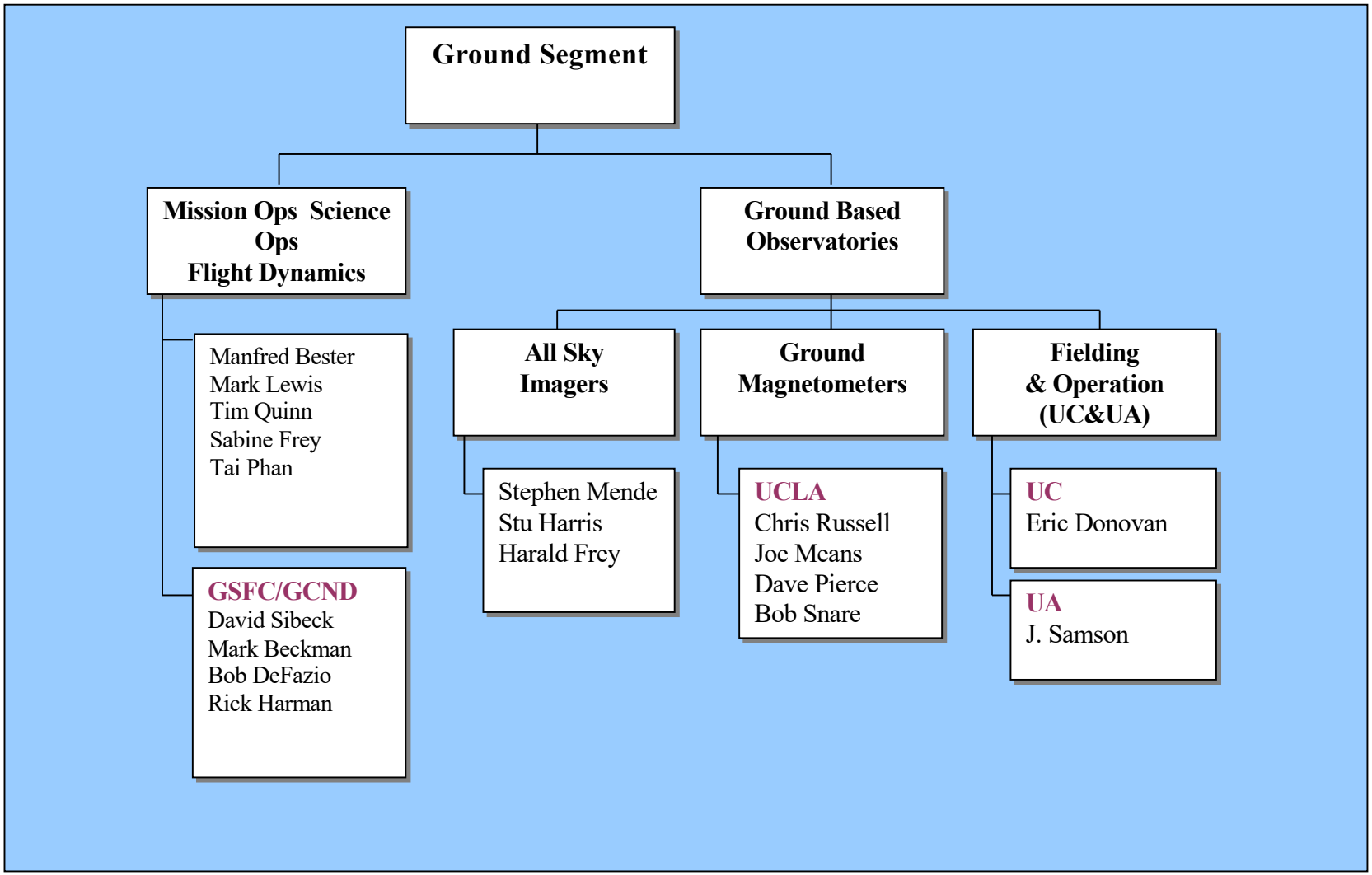
Organization Chart



Instruments Team Organization



GBO Team Organization



Mission Overview

Launch

Vehicle:	Delta II, Eastern Range
Apogee:	91845.2 km ± 9567 km
Perigee:	435 km ± 10 km (500 km ± 7 km on or after 3/1/2007)
Inclination:	16.0 deg ± 0.5 deg
Date:	February 17, 2007

Space Segment

Spacecraft:	5 Identical Spinning Probes with Fuel for Orbit & Attitude Adjust
Instruments:	3-Axis Electric Field, Magnetic Field 3-D Ion & Electron Particle Detectors
Spin Rate:	20 RPM
Orbit Period(s):	1, 2 and 4 days
Orientation:	Ecliptic Normal

Ground Segment

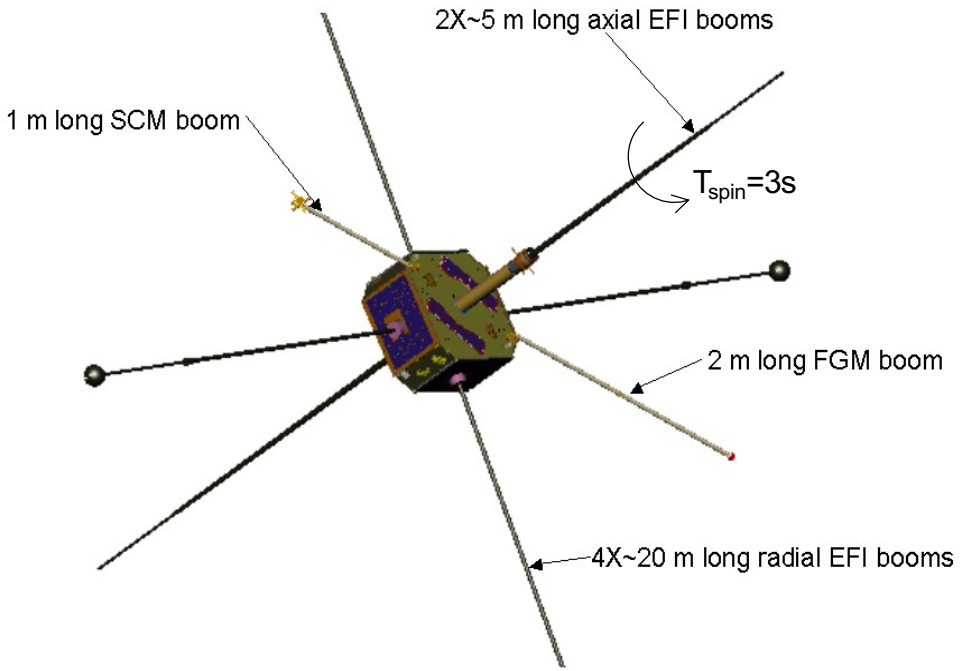
Observatories:	20 Northern with All Sky Imagers and Magnetometers
Control Facilities:	Mission and Science Operations Centers

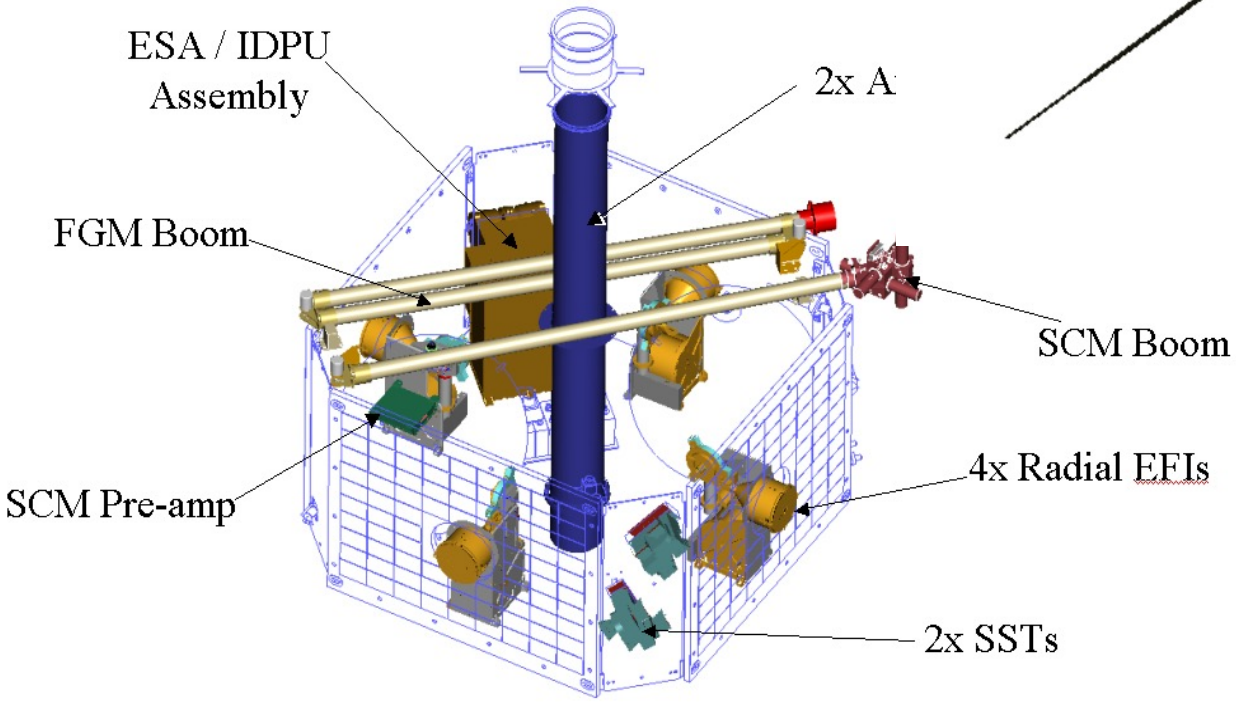
Operations

Phases:	L&EO, Cruise, Ascent, Campaigns, De-orbit
Lifetime:	2.5 years

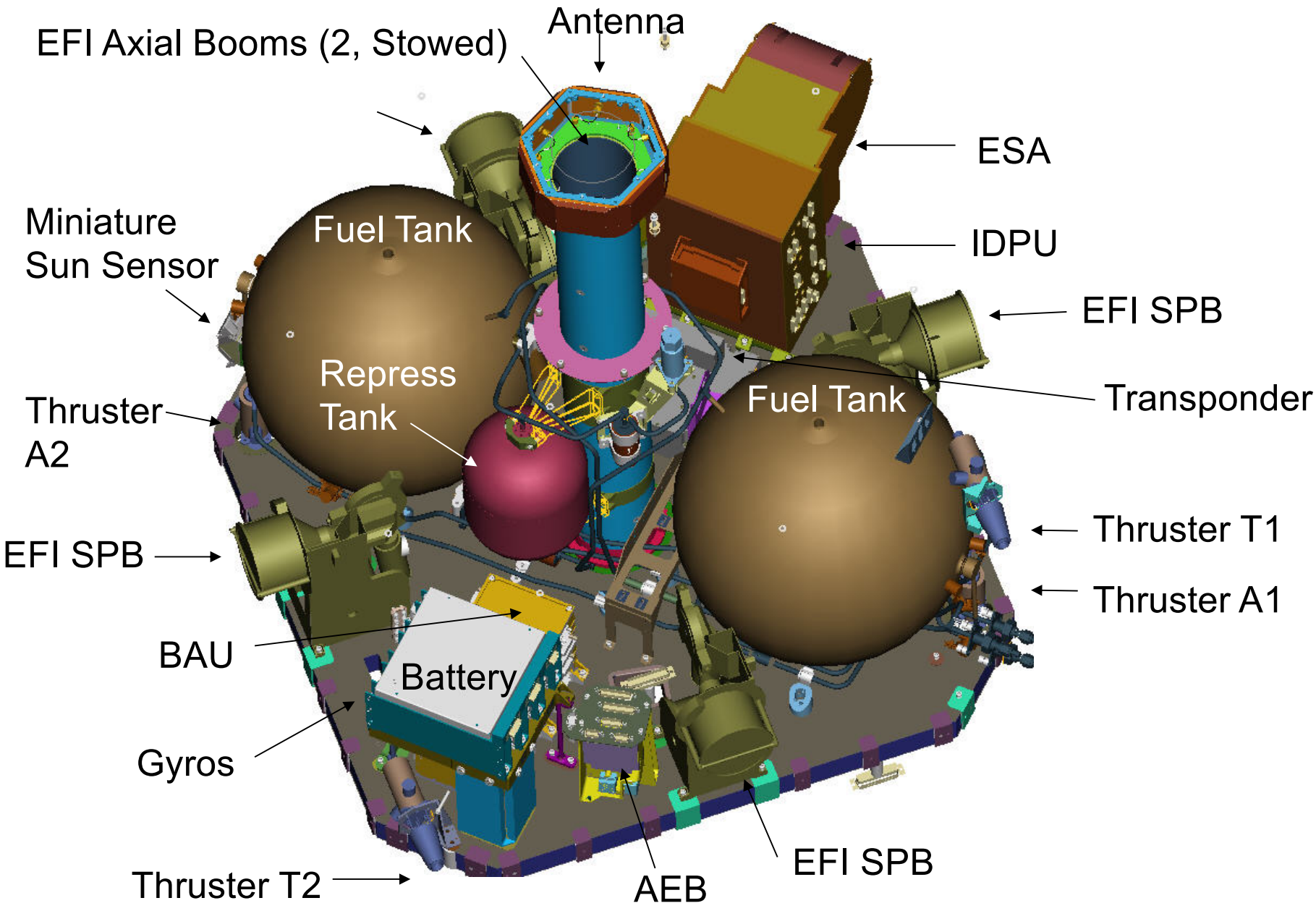
Instrument Configuration

IDPU: Instrument Data Processor Unit
SPB : Spin Plane Booms (4x)
AXB : Axial Booms (2x)
SST : Solid State Telescope (2x)
ESA : Electrostatic Analyzer
FGM : Fluxgate Magnetometer
SCM : Search Coil Magnetometer





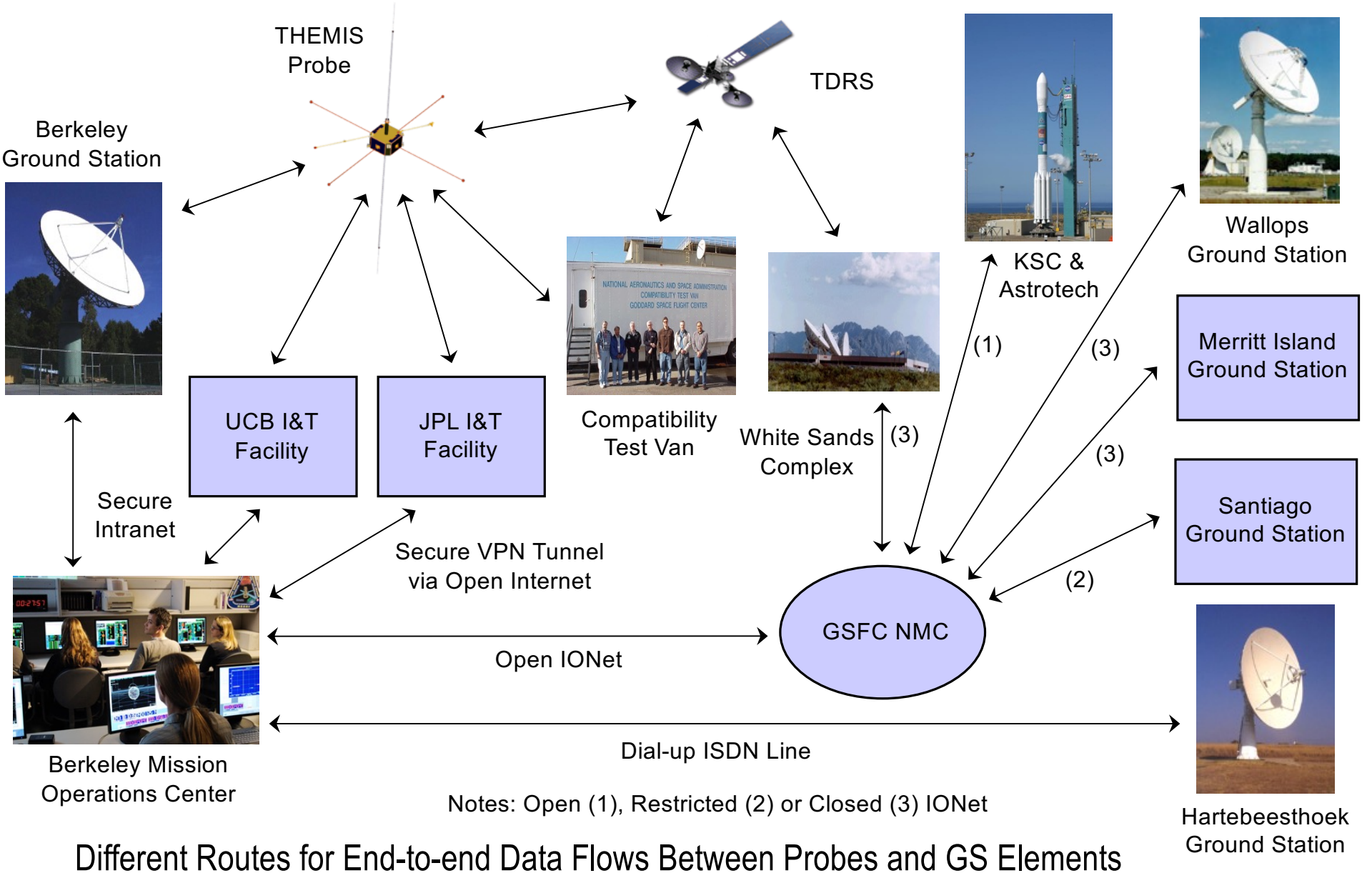
Probe Configuration: Tight, Custom



Delta II 7925 Launch Vehicle

10 Fairing

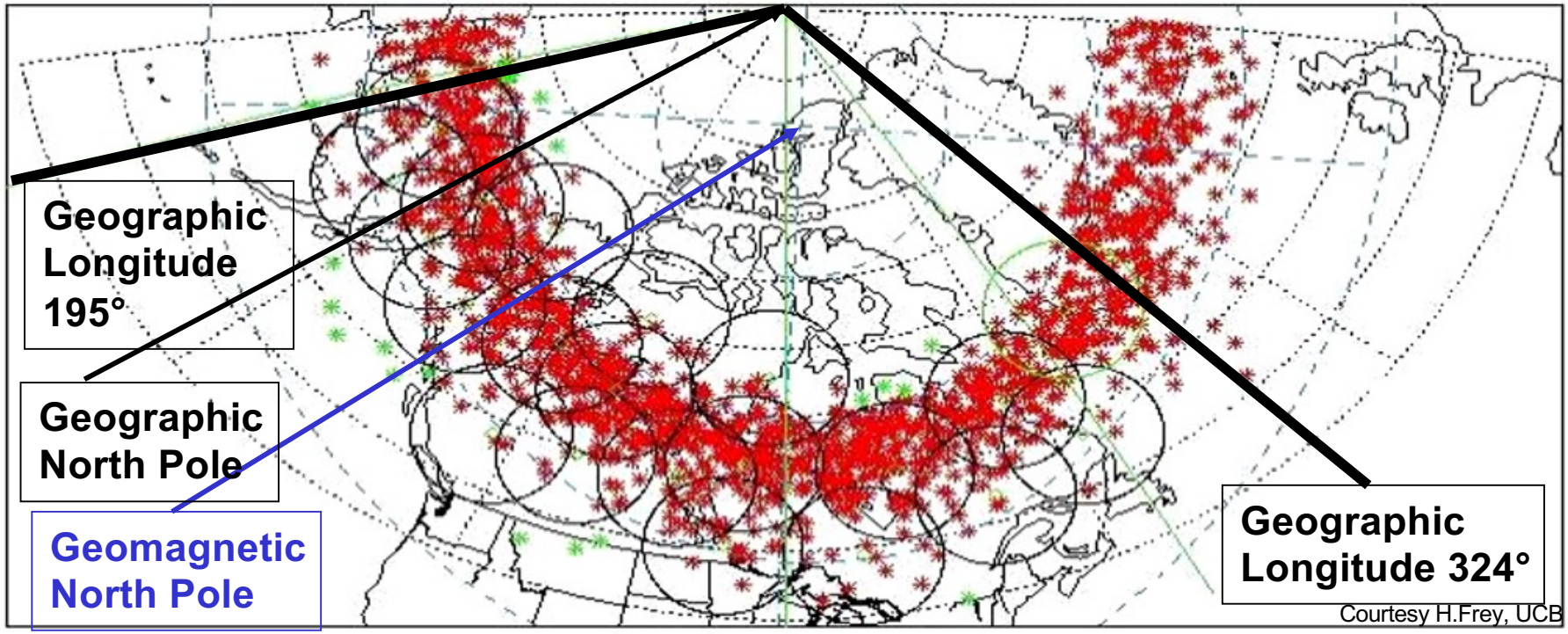
Mission Data Flows to MOC at UCB



Different Routes for End-to-end Data Flows Between Probes and GS Elements

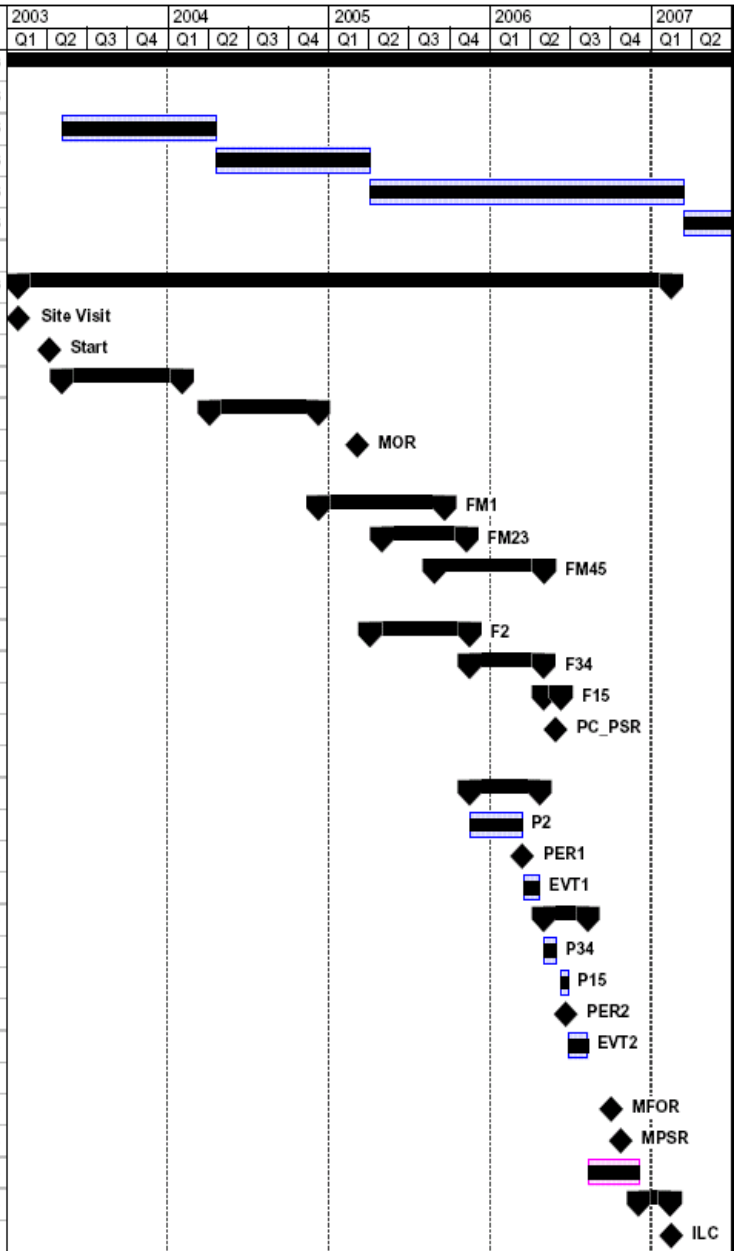
Ground Based Observatories

- UCB/UCLA Delivered All 20 GBO (GMAG and ASI) units
- Deployed and operated by Canadian Space Agency (Calgary)
- Automatic Data Collection and Archiving in Progress
- Remote Commanding and Diagnostics Working

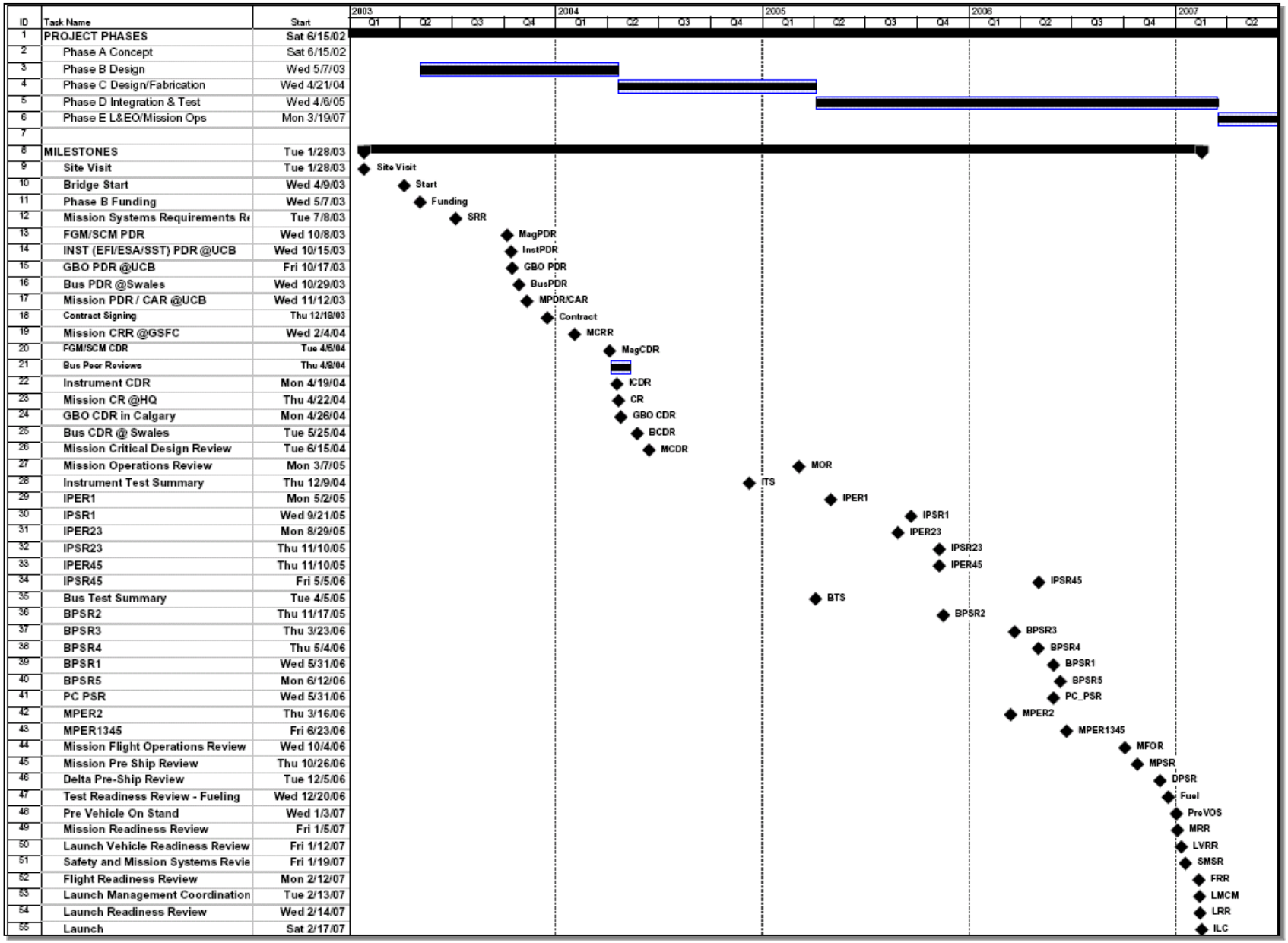


Schedule

ID	Task Name	Start	Finish	Duration
1	**PROJECT PHASES**	**Sat 6/15/02**	**Fri 9/11/09**	**378.4 wks**
2	Phase A Concept	Sat 6/15/02	Wed 10/16/02	17.5 wks
3	Phase B Design	Wed 5/7/03	Tue 4/20/04	50 wks
4	Phase C Design/Fabrication	Wed 4/21/04	Tue 4/5/05	50 wks
5	Phase D Integration & Test	Wed 4/6/05	Fri 3/16/07	102 wks
6	Phase E L&EO/Mission Ops	Mon 3/19/07	Fri 9/11/09	130 wks
7				
8	**MILESTONES**	**Tue 1/28/03**	**Sat 2/17/07**	**212 wks**
9	**Site Visit**	**Tue 1/28/03**	**Tue 1/28/03**	**0 wks**
10	**Bridge Start**	**Wed 4/9/03**	**Wed 4/9/03**	**0 wks**
11	**Preliminary Design**	**Wed 5/7/03**	**Wed 2/4/04**	**39 wks**
21	**Detailed Design, Fab**	**Tue 4/6/04**	**Thu 12/9/04**	**35.4 wks**
30	**Mission Operations Review**	**Mon 3/7/05**	**Mon 3/7/05**	**0 wks**
31	**Instrument I&T**	**Thu 12/9/04**	**Fri 5/5/06**	**73.2 wks**
32	**FM1 I&T**	**Thu 12/9/04**	**Wed 9/21/05**	**40.8 wks**
36	**FM23 I&T**	**Mon 5/2/05**	**Thu 11/10/05**	**27.6 wks**
40	**FM45 I&T**	**Mon 8/29/05**	**Fri 5/5/06**	**35.8 wks**
44	**Probe Bus I&T**	**Tue 4/5/05**	**Mon 6/12/06**	**61.8 wks**
45	**F2 I&T**	**Tue 4/5/05**	**Thu 11/17/05**	**32.4 wks**
48	**F34 I&T**	**Thu 11/17/05**	**Thu 5/4/06**	**24 wks**
52	**F15 I&T**	**Thu 5/4/06**	**Mon 6/12/06**	**5.4 wks**
56	**PC PSR**	**Wed 5/31/06**	**Wed 5/31/06**	**0 wks**
57				
58	**First Probe**	**Thu 11/17/05**	**Mon 4/24/06**	**22.6 wks**
59	**I&T (Probe2)**	**Thu 11/17/05**	**Wed 3/15/06**	**17 wks**
60	**PER (Probe2)**	**Thu 3/16/06**	**Thu 3/16/06**	**0 wks**
61	**EVT (Probe 2)**	**Mon 3/20/06**	**Mon 4/24/06**	**5.2 wks**
62	**All the Rest**	**Thu 5/4/06**	**Fri 8/11/06**	**14.4 wks**
63	**I&T (Probes34)**	**Thu 5/4/06**	**Wed 5/31/06**	**4 wks**
64	**I&T (Probes15)**	**Mon 6/12/06**	**Wed 6/28/06**	**2.5 wks**
65	**PER (All Probes)**	**Fri 6/23/06**	**Fri 6/23/06**	**0 wks**
66	**EVT (All Probes)**	**Thu 6/29/06**	**Fri 8/11/06**	**6.4 wks**
67				
68	**Mission Flight Operations Review**	**Wed 10/4/06**	**Wed 10/4/06**	**0 wks**
69	**Mission Pre Ship Review**	**Thu 10/26/06**	**Thu 10/26/06**	**0 wks**
70	**Launch Delay**	**Mon 8/14/06**	**Tue 12/5/06**	**16.5 wks**
71	**Launch Campaign**	**Tue 12/5/06**	**Wed 2/14/07**	**10.2 wks**
81	**Launch**	**Sat 2/17/07**	**Sat 2/17/07**	**0 wks**



Major Reviews



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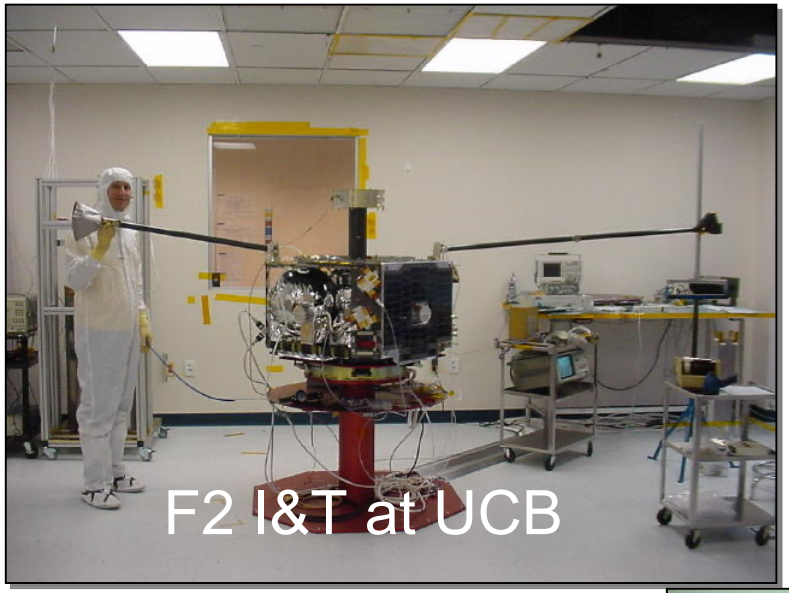
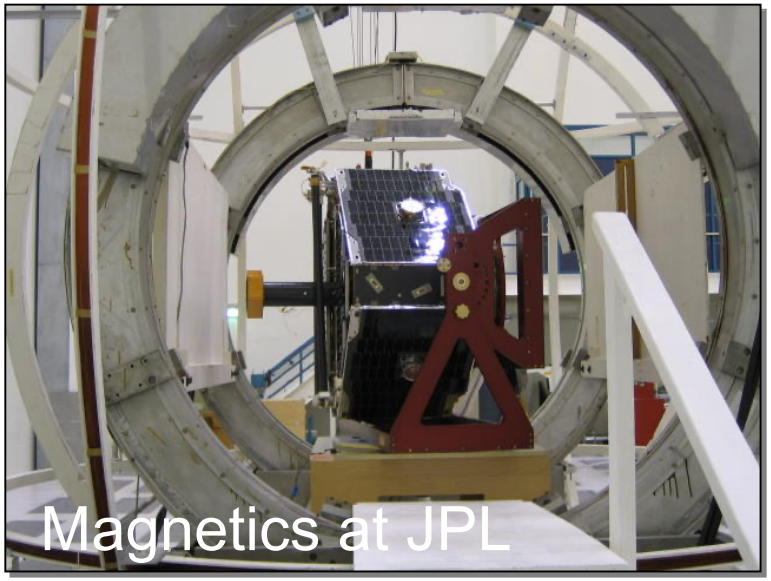
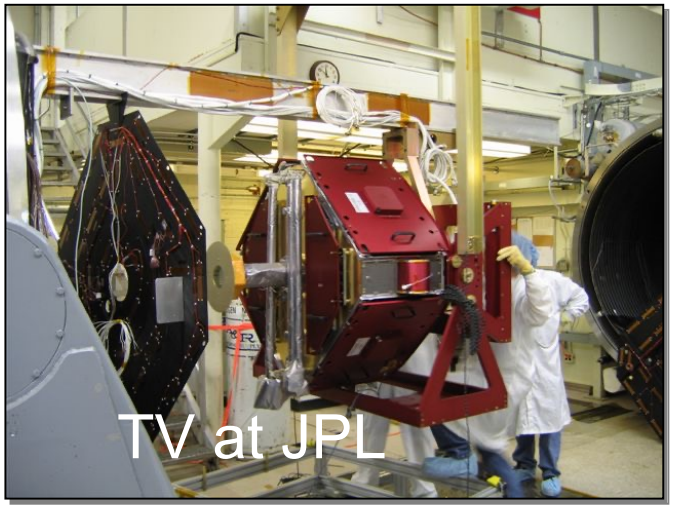
5	Phase D Integration & Test	Wed 4/6/05
6	Phase E L&EO/Mission Ops	Mon 3/19/07
7		
8	MILESTONES	Tue 1/28/03
9	Site Visit	Tue 1/28/03
10	Bridge Start	Wed 4/9/03
11	Phase B Funding	Wed 5/7/03
12	Mission Systems Requirements Re	Tue 7/8/03
13	FGM/SCM PDR	Wed 10/8/03
14	INST (EFI/ESA/SST) PDR @UCB	Wed 10/15/03
15	GBO PDR @UCB	Fri 10/17/03
16	Bus PDR @Swales	Wed 10/29/03
17	Mission PDR / CAR @UCB	Wed 11/12/03
18	Contract Signing	Thu 12/18/03
19	Mission CRR @GSFC	Wed 2/4/04
20	FGM/SCM CDR	Tue 4/6/04
21	Bus Peer Reviews	Thu 4/8/04
22	Instrument CDR	Mon 4/19/04
23	Mission CR @HQ	Thu 4/22/04
24	GBO CDR in Calgary	Mon 4/26/04
25	Bus CDR @ Swales	Tue 5/25/04
26	Mission Critical Design Review	Tue 6/15/04
27	Mission Operations Review	Mon 3/7/05
28	Instrument Test Summary	Thu 12/9/04
29	IPER1	Mon 5/2/05
30	IPSR1	Wed 9/21/05
31	IPER23	Mon 8/29/05
32	IPSR23	Thu 11/10/05
33	IPER45	Thu 11/10/05
34	IPSR45	Fri 5/5/06
35	Bus Test Summary	Tue 4/5/05
36	BPSR2	Thu 11/17/05
37	BPSR3	Thu 3/23/06
38	BPSR4	Thu 5/4/06
39	BPSR1	Wed 5/31/06
40	BPSR5	Mon 6/12/06
41	PC PSR	Wed 5/31/06
42	MPER2	Thu 3/16/06
43	MPER1345	Fri 6/23/06
44	Mission Flight Operations Review	Wed 10/4/06
45	Mission Pre Ship Review	Thu 10/26/06
46	Delta Pre-Ship Review	Tue 12/5/06
47	Test Readiness Review - Fueling	Wed 12/20/06
48	Pre Vehicle On Stand	Wed 1/3/07
49	Mission Readiness Review	Fri 1/5/07
50	Launch Vehicle Readiness Review	Fri 1/12/07
51	Safety and Mission Systems Revie	Fri 1/19/07
52	Flight Readiness Review	Mon 2/12/07
53	Launch Management Coordination	Tue 2/13/07
54	Launch Readiness Review	Wed 2/14/07
55	Launch	Sat 2/17/07

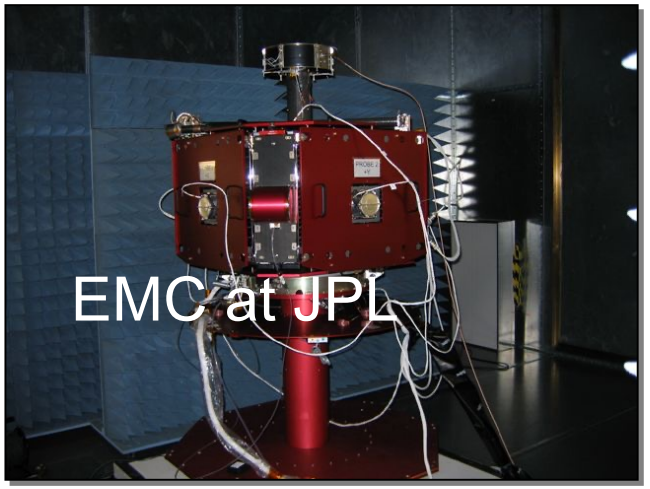
Probe 2 I&T: The trailblazer. First at JPL, for end-to-end testing


F2 I&T at UCB

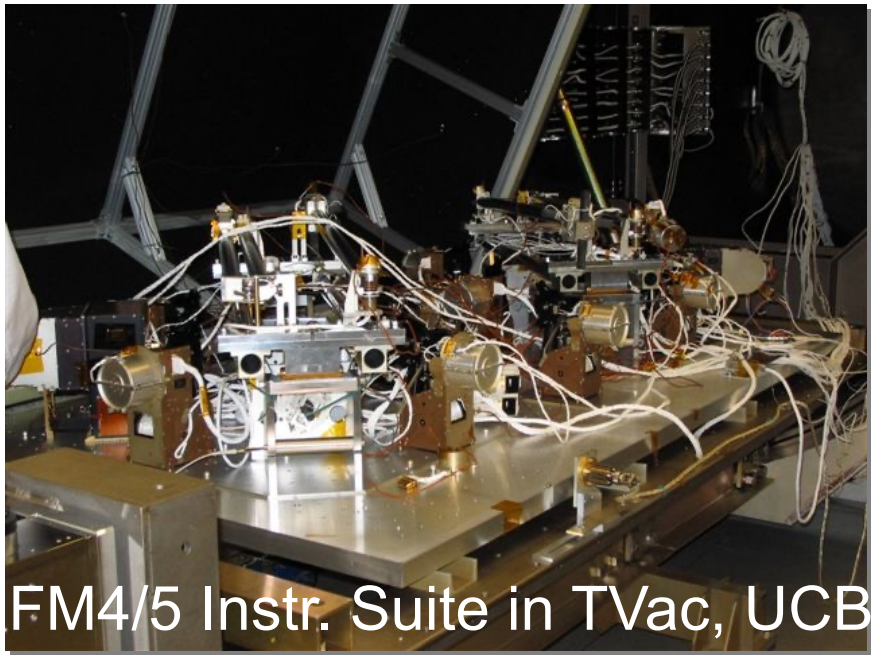

Magnetics at JPL

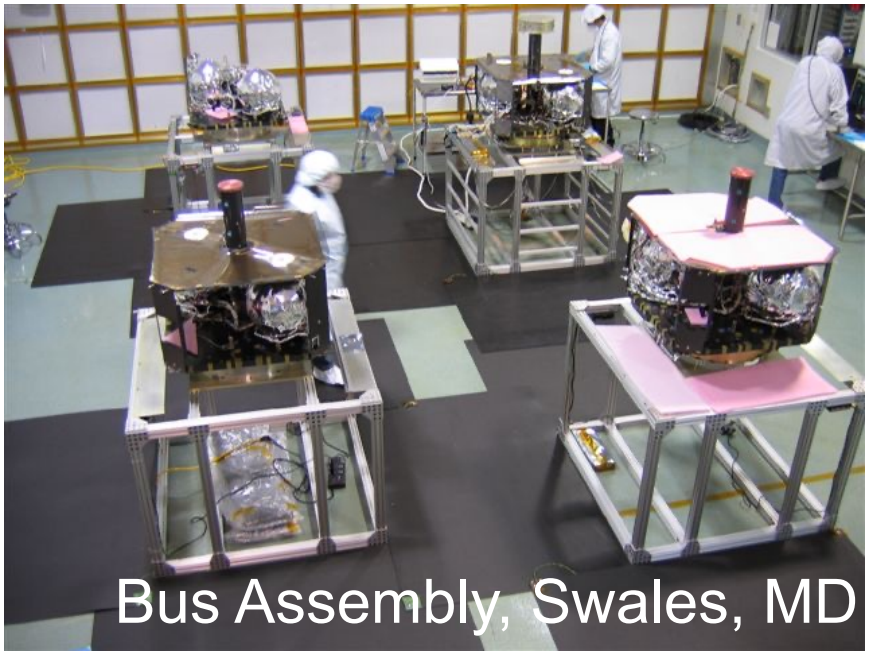

TV at JPL


VIB at JPL


EMC at JPL

Probes 1,3,4,5 I&T

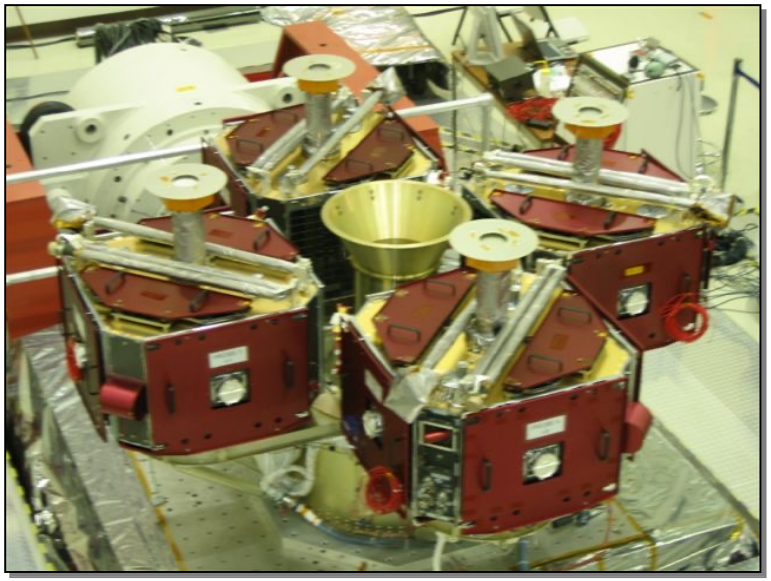

FM4/5 Instr. Suite in TVac, UCB

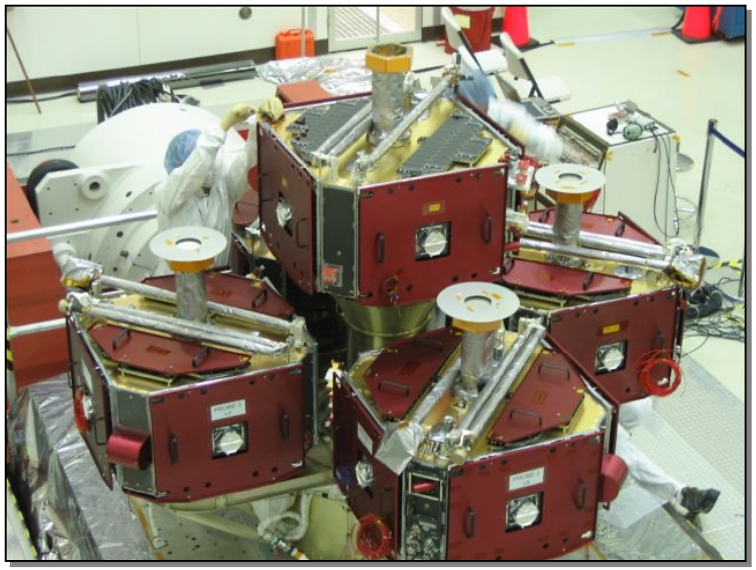

Bus Assembly, Swales, MD


Probe Integration, UCB

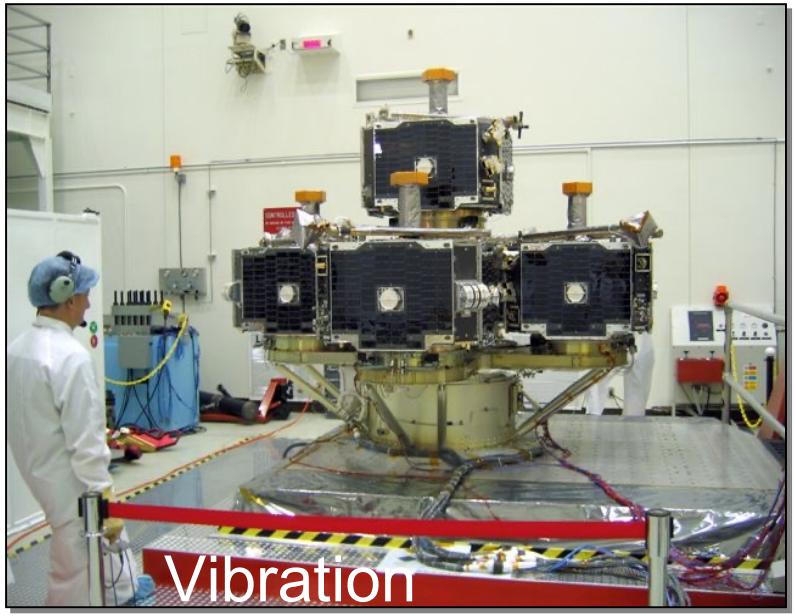
JPL2 PCA Buildup

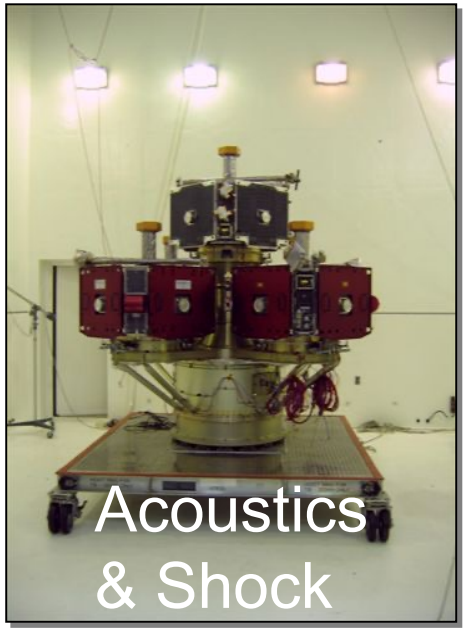
PCA Assembly and Test

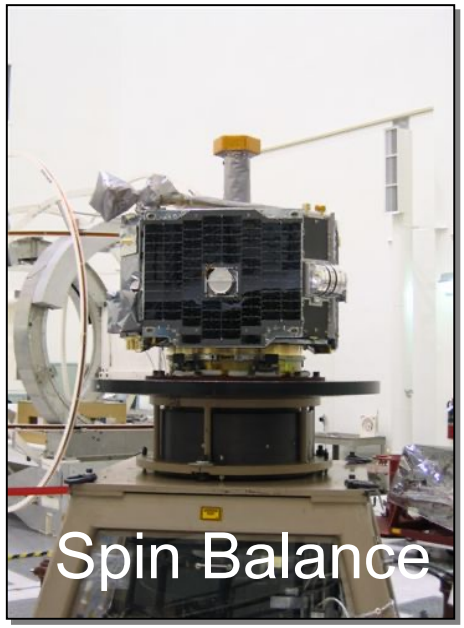


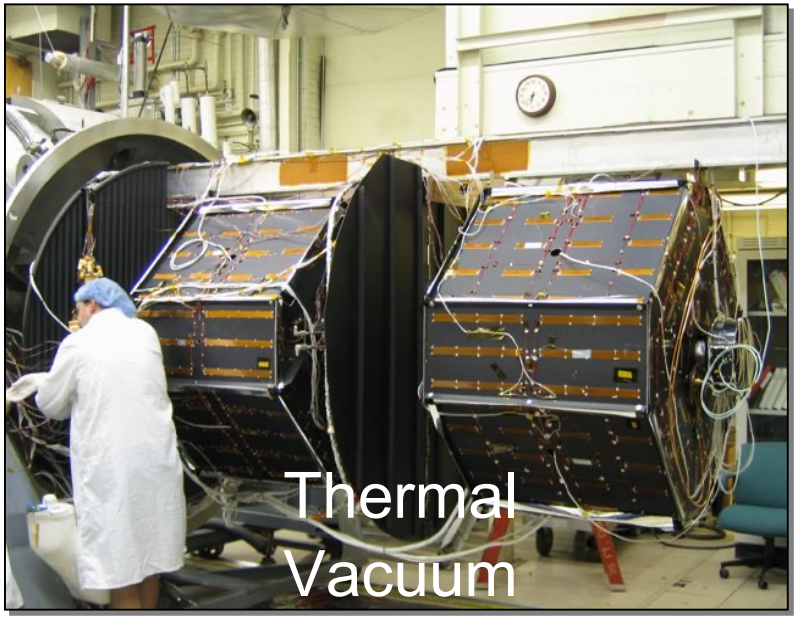


JPL2 Environments





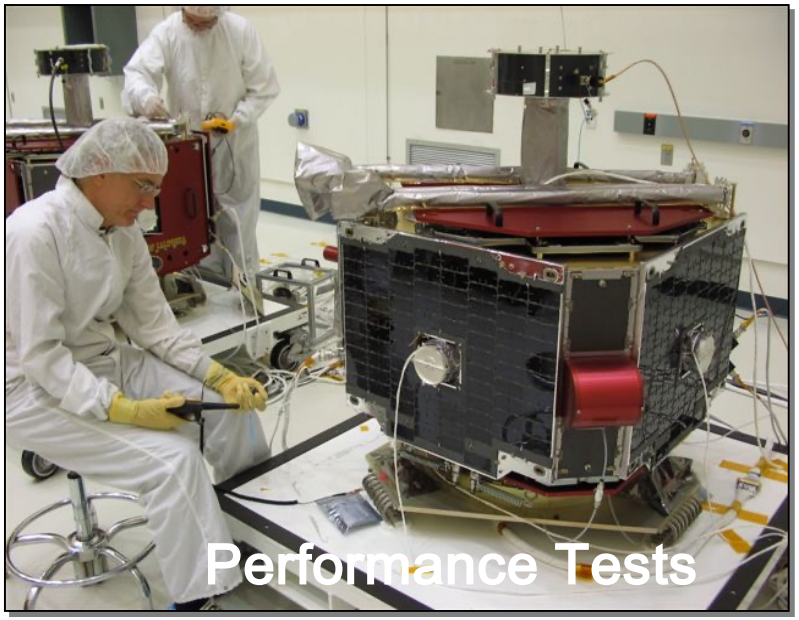


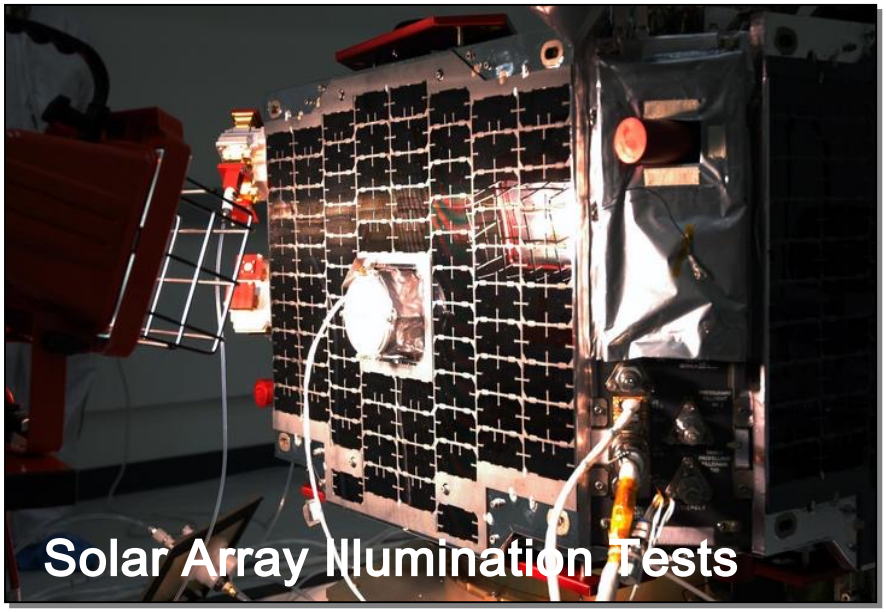


ASO Probe Processing

Delivery to ASO in FL

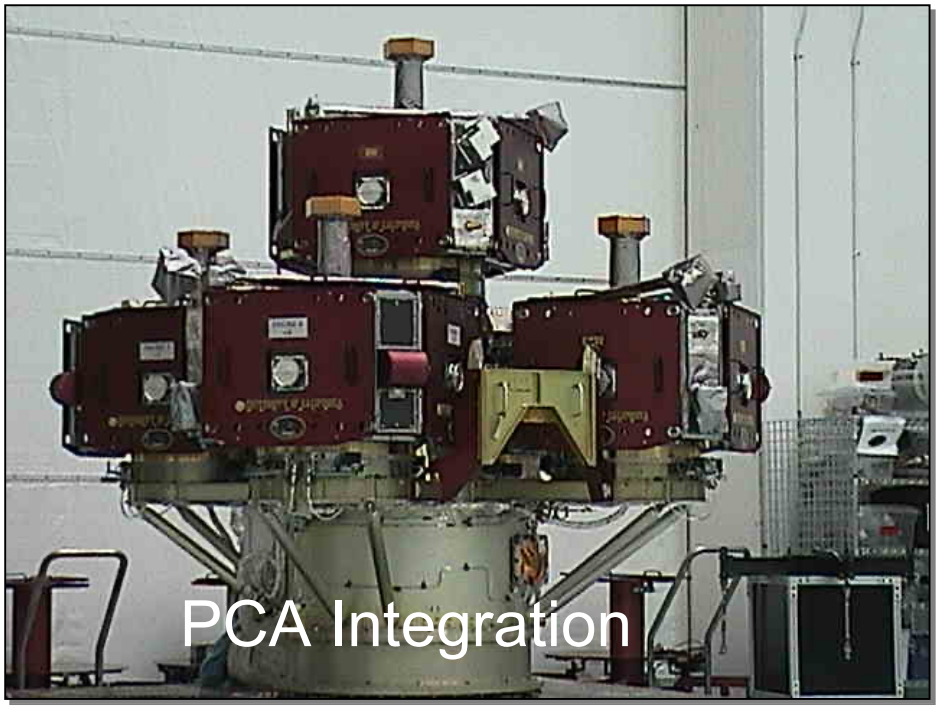

Bolt Cutter Installation

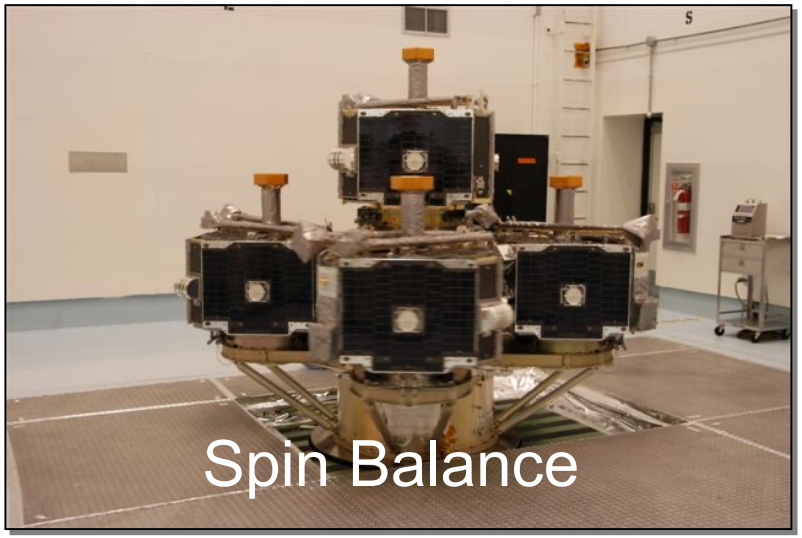

Performance Tests


Solar Array Illumination Tests

ASO Probe Fueling

ASO PCA Processing

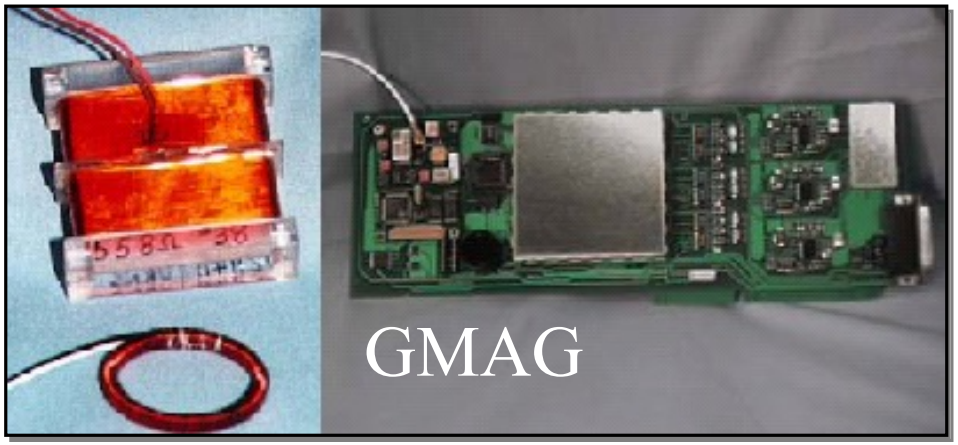




Ground Based Observatories already operational by THEMIS launch


Production line @ UCB

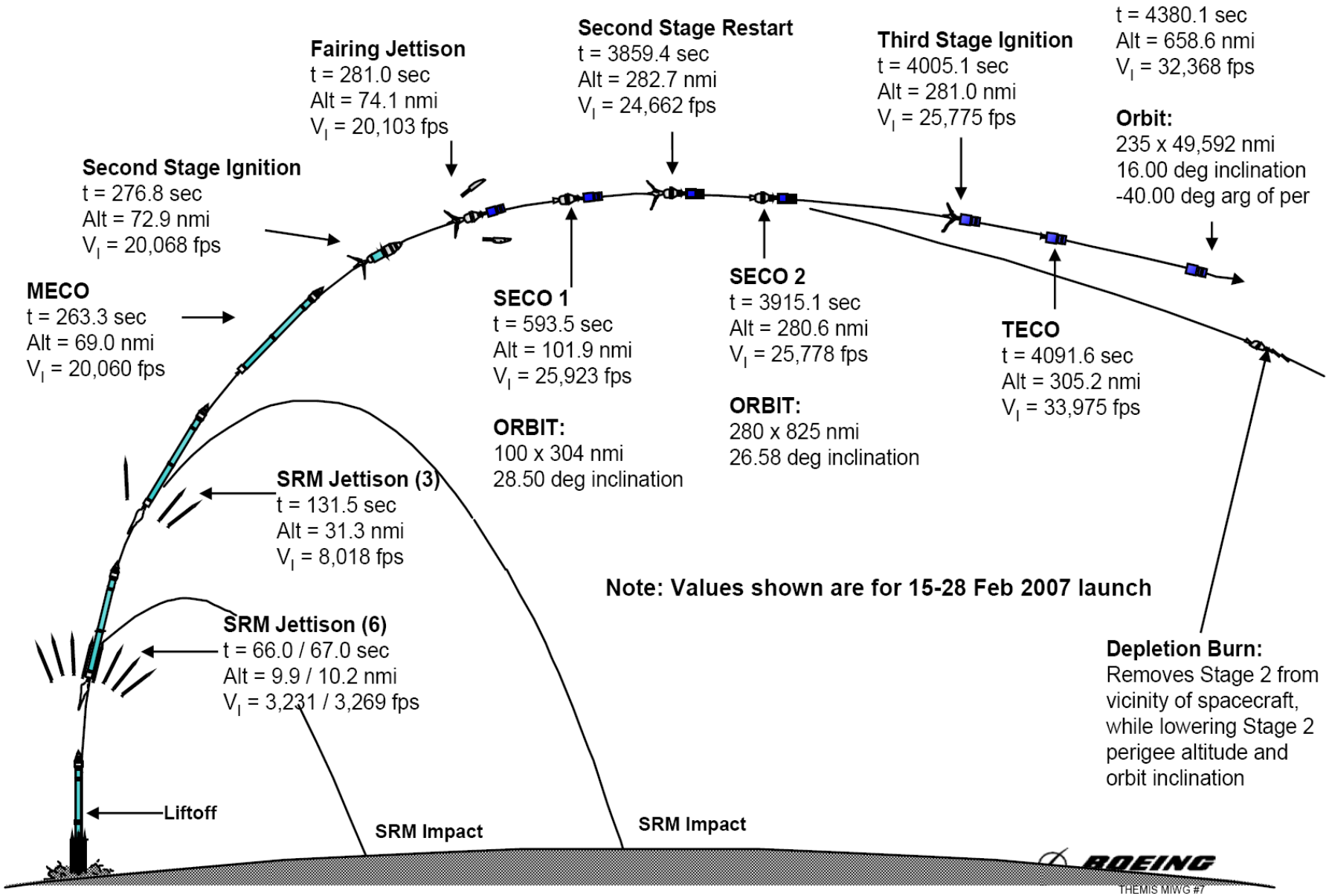

Fort Yukon, AK, site


GMAG

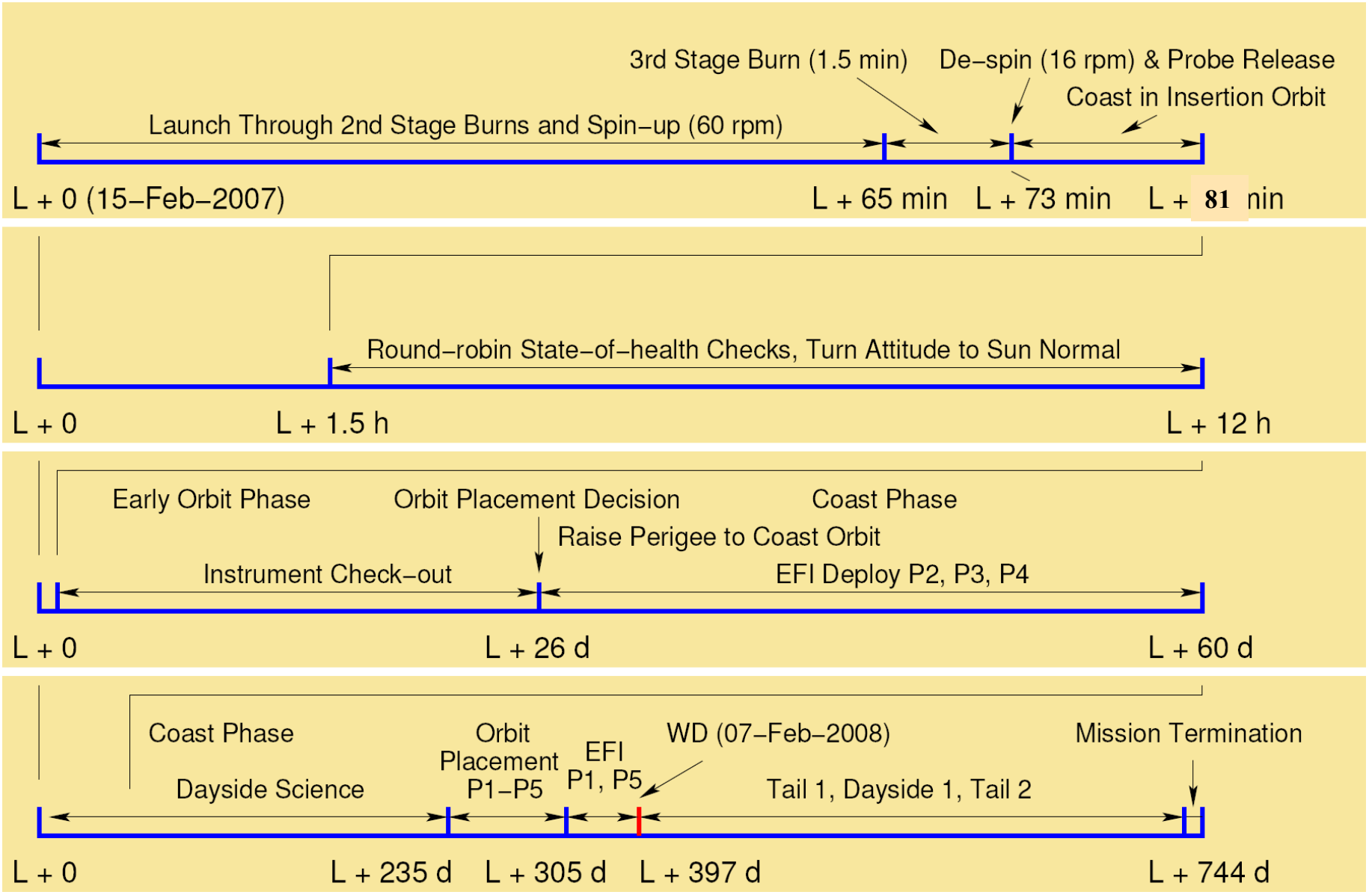

ASI


EPO GMAG

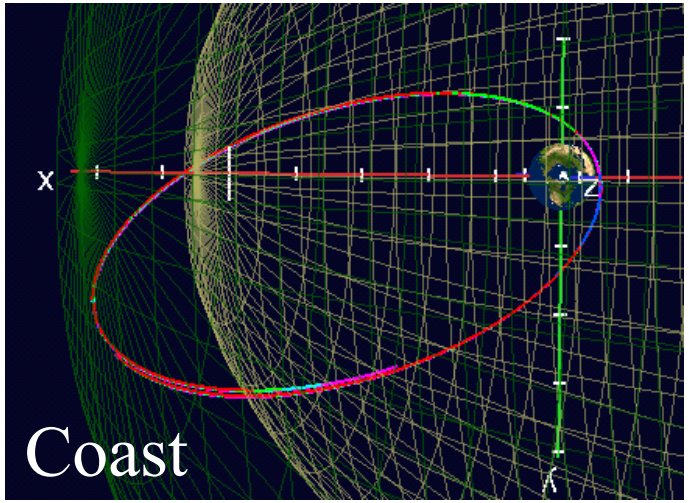
Flight Profile



Mission Profile



Orbit Plans



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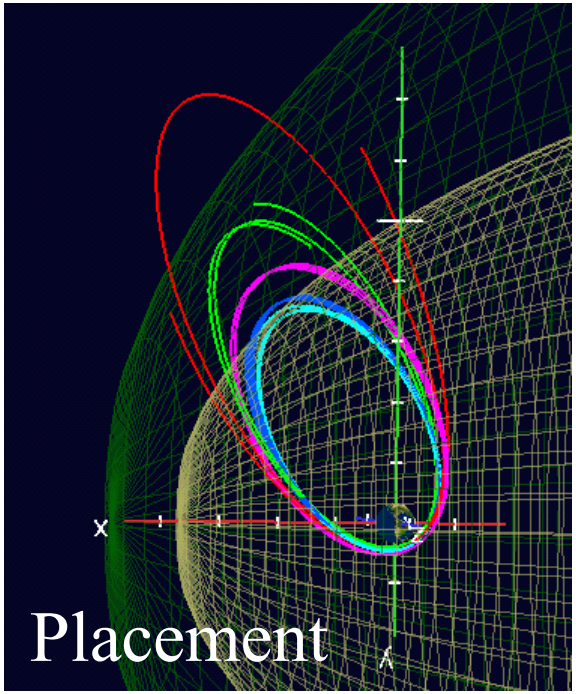
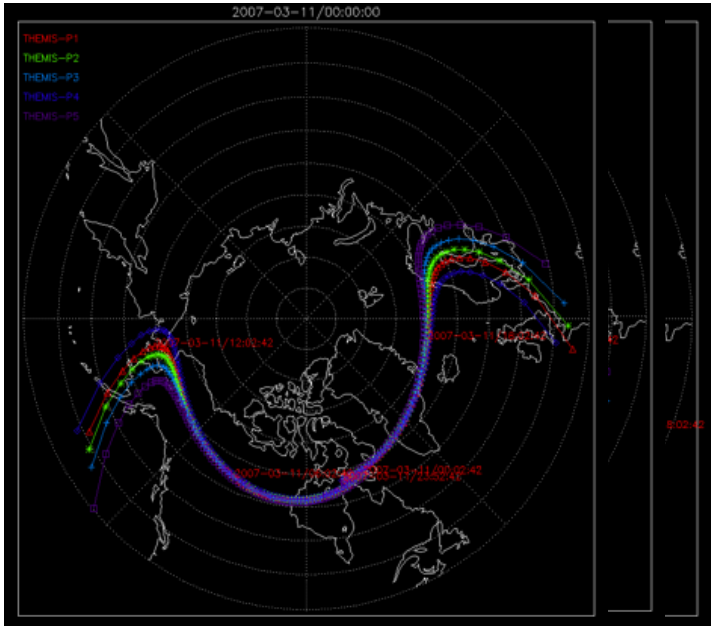
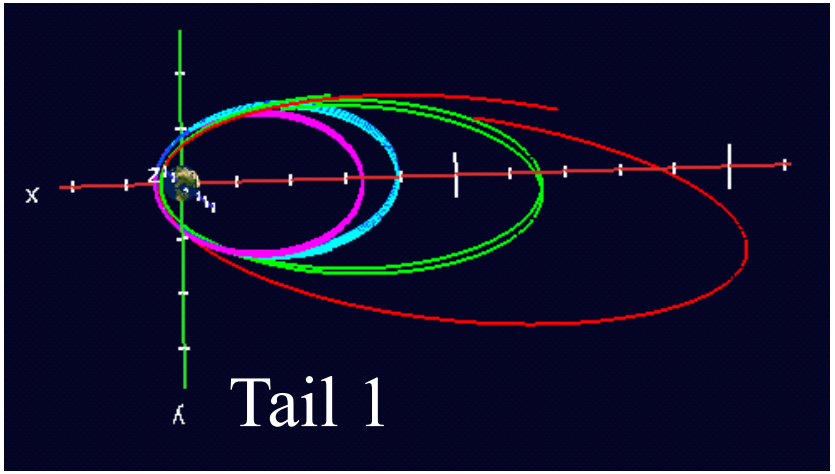






http://sscweb.gsfc.nasa.gov/tipsod/

Probe Placement Decision

- Assigned Constellation IDs (P1−P5) to Probe Buses

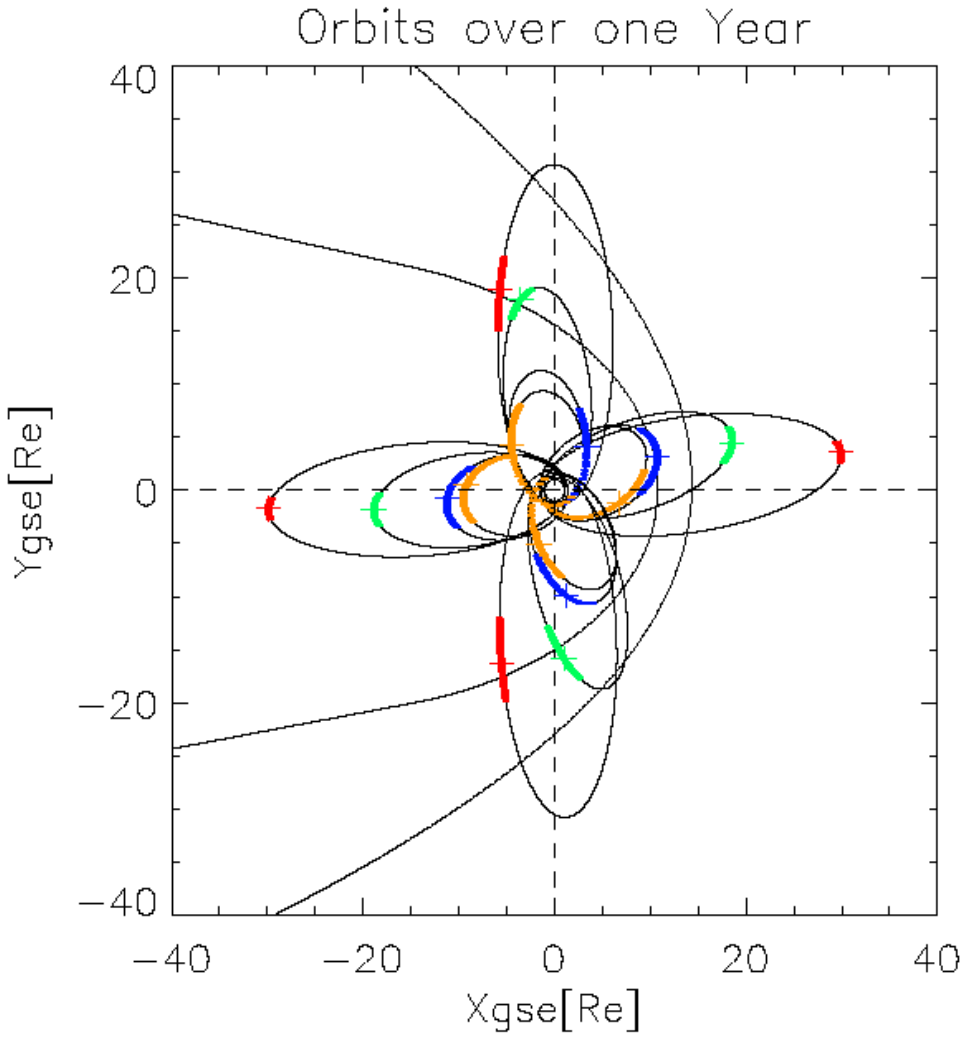
THEMIS A −> P5
THEMIS B −> P1
THEMIS C −> P2
THEMIS D −> P3
THEMIS E −> P4

- Decision Based on Probe Bus and Instrument Performance
  - Also Included Performance Details Found During Ground Testing
  - Only Differences Noted Are in Telecom System

- Team Members Involved in Probe Placement Decision
  - PI, PM, MSE, MOM, MDL, Swales Probe Bus Systems Lead, Instrument Scientists, GSFC Program Manager and GSFC Project Scientist

First Year at a Glance

Predicted conjunctions exceed 188hrs/season with ~50% margin



Performance Failure Reports (PFRs)

Sequence of Events

- Probe Bus A flow halted at Swales
- Probe Bus B, Inst B integrated first
- Completed Probe B before Integrating the rest
- Sequence: B-CDEA or 2-3451

PFR Summary	PFRs	Sing	Mul	Acts
Probe	46	34	12	91
Instrument	141	87	54	337
FSW	16	3	13	68
GSE	29	20	9	54
Total	**232**	**144**	**88**	**550**

I&T PFR Uniques	B	C	D	E	A
Probe	22	2	1	1	5
Instrument	22	20	5	7	13
FSW	0	0	2	0	1
GSE	6	3	6	3	-
Total	50	25	14	11	19

Top Technical Problems

Bus Dvlpmt 8/2004 Mass growth. Adopted ingenious RCS repressurized design. ←

Bus Dvlpmt 12/2004 Probe 1 Deck Fabrication Problems (3-ply carbon)←

- GSFC Panel Oversight Committee, solved w/ GSFC help

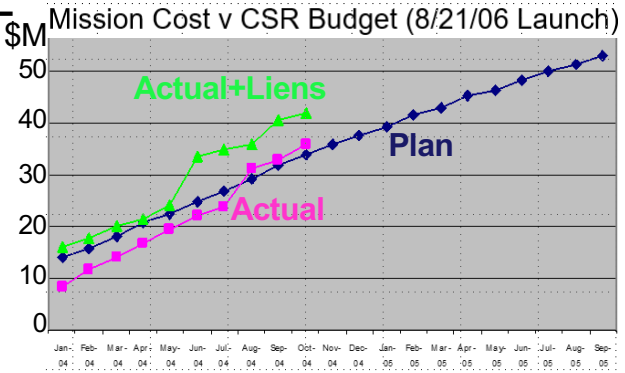
Bus Dvlpmt Thermal design dicey. All thermal hands-on deck ←

Probe I&T BAU hang-ups (resets) frequent (accepted)

Probe I&T 04/2005 Schedule Risk Increased; Cost Growth >25% ←

Mtg w/ MM @GSFC; Req'd Mgmt Changes Under Threat of Cancellation:

- SAI delivered V&V'ed buses & support thru L&EO + Ph-E
- UCB took bus deliveries and Mission I&T (@JPL & @KSC)



Probe I&T 04/2006 All Transponders exhibited Pure Tin Lugs, Filter Noise, Diplexor Vibe Failure, Arcing ←

- All transponders Mod'ed for Venting Modification and Retest
- I&T proceeded with P2 transponder fixed first, to become the trailblazer, saving the schedule

Environments Probe 2 Fuel Line Backup thermostat too close to spec limit

Environments All EFI Axial Boom Covers Contaminated

Pre-Launch All EFI Preamp Capacitors Needed Replacement

Management Issues
Page#1: Proposed in CSR

D3. Management: Experienced teams with clear lines of authority and responsibility.

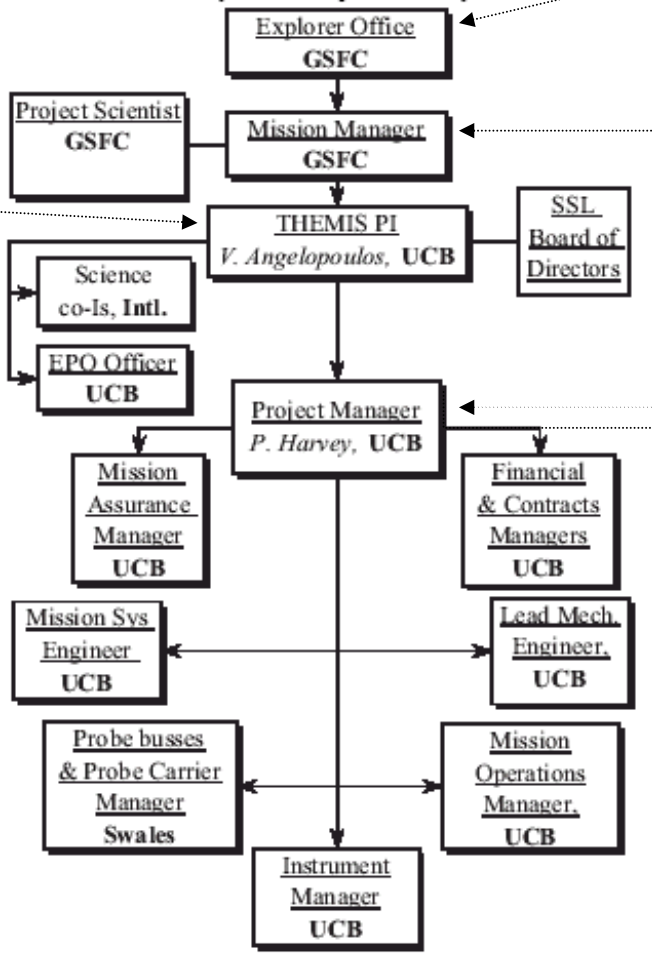


Figure D-3 THEMIS organizational structure.

The mission is managed by UCB, an institution that has successfully led three previous Explorer missions (EUVE, FAST and HESSI) and has >30 years of experience in managing large programs for NASA and other organizations. THEMIS core team

Sets Explorer Guidelines, (based on GSFC practices), reports to GPMC and HQ
Ensures adherence to margins,resources and requirements committed to by PI (e.g., INST-001).
If margins are threatened, GSFC recommends action, offers resources, takes on more active role in technical decisions and resource management.

Responsibility and authority to conduct investigation within proposed resources. Delegates daily management to PM. Reports to GSFC (resource and science margins) and HQ (decisions that affect L1).

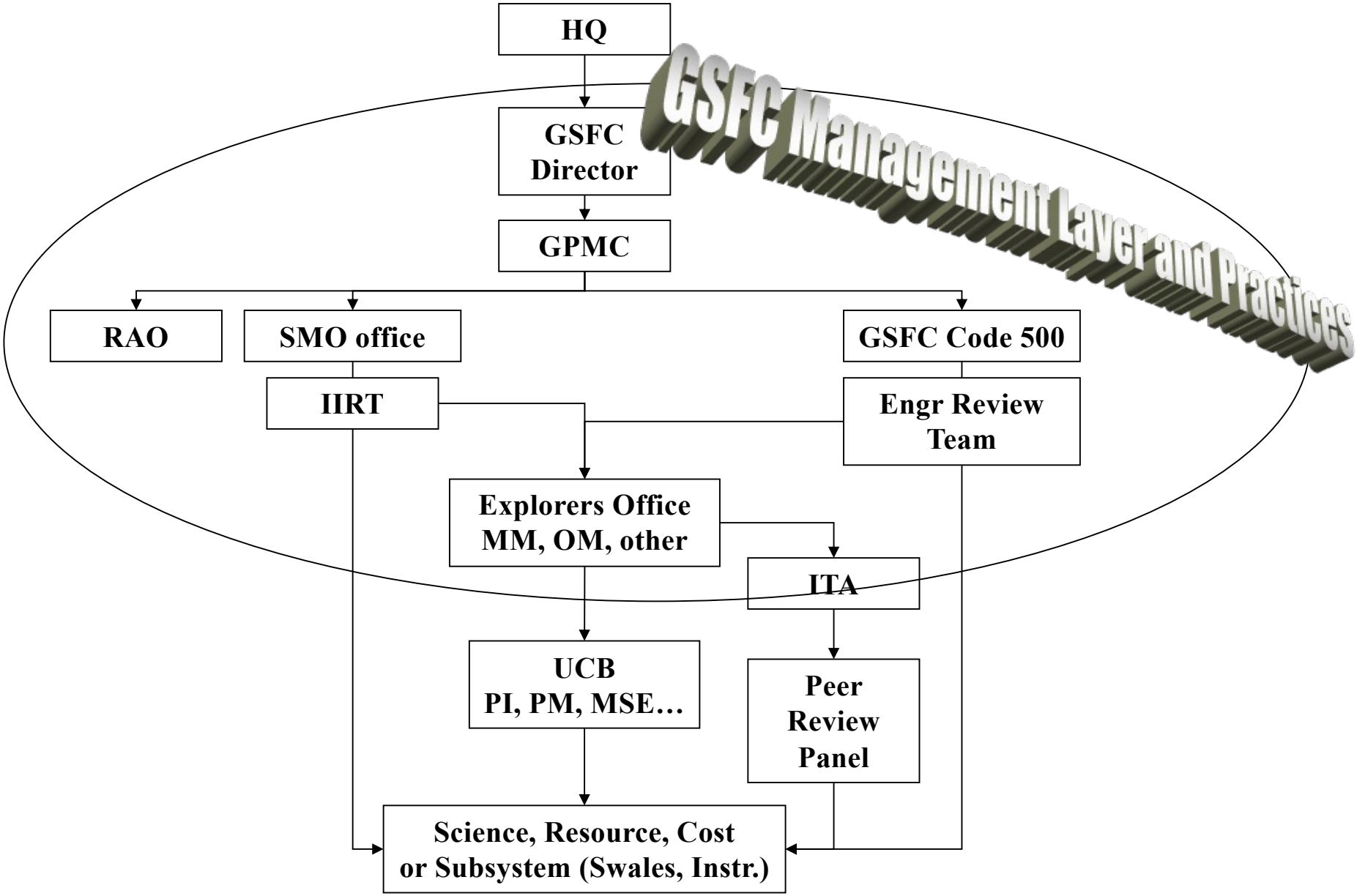
Day-to-day program management for the PI, within allocated resources. Science/Technical decisions involve PI. Reports resource trends and margins to PI and Explorers office.

Review teams: Peer, IIRT

IIRT (formal): Ensures, for MM, technical, schedule and cost margins are met. Recommends but does not enforce actions to PM.
An asset for both MM and PM.
Disposition of actions within PM authority.

Peer (informal): Ferrets out issues before they become problems. Disposition within subsystem.
Ultimate closure of issues by PM.

Management Issues. Page#2: Implemented at Confirmation



Management Issues. Page#3: Adjustment to the New Reality

Reason for change:

GSFC was told by HQ that center has responsibility for project success.
GSFC took seriously its authority to ensure mission success, treating THEMIS as internal GSFC mission, managed in accordance with GSFC management practices and heritage.

Effects:

- GSFC became involved with subsystems
  - Involvement often construed as direction, partly due to pre-existing relations
- GPMC started requiring own management practices and heritage
  - Cost adherence no longer a priority (HQ picked mission!)
  - Risk-aversion addressed thru formal review channels to drive decisions
  - Resources and trades discussed openly with subs, outside of PI sphere
  - Mitigation plans required center review and approval
  - Organization changes took a long time to make and were perceived risky

Practical Resolution:

- Constant, open, direct communications between PI-PM and MM incl. Explorers office
- Cultivated amicable working relationship w/ capable team members to resolve issues
- Capitalized on strong THEMIS ties with Explorers to reinforce trust and instill efficient interactions

Management Issues: Page#4: Lessons Learned

Projectize Team, Build Trust, Ensure Clear & Efficient Communications

- Recognize GSFC holds the contract and go with the flow – embrace and turn it into an asset!
- Agree with contractors and GSFC on “terms of engagement” (even if moot point)

  - Emphasize team-effort
- Emphasize strategic successes (as opposed to tactical ones) – use science to motivate.

  - Pick main battles where it matters: on technical and science issues
- Information is key: obtain as much of it as possible from both GSFC and subcontractors
- Open and honest communication between PI-PM and MM (on e.g.: parallel paths, costs & projections)
- Call out and tabulate out-of-scope items; insist only on heavy-hitters

Summary of Main Problems and Responses

	Rather than:	Responded:
COM loss at launch	"It's on the LV / NORAD"	Issued emergency, worked with all national assets, as per well-rehearsed plan.
Mass growth	Upsize ($$) or accept (SCI)	Instruments accommodated a new tank
Thermal design didn't close	Restrict s/c attitudes (risk)	Instrument-bus personnel solved together
Cost/schedule risk	Delay launch ($$, SCI)	Execute backup MI&T venue (org-chart)
Transponder-related delays	OK, it was tough to do ($$)	Reorganize MI&T to stay on schedule
IIRT reports risks to center (Driven not by cost/schedule but only risk aversion)	Naturally accept.	Worked with MM and GSFC resources to anticipate, preempt, and diffuse concerns (Embraced MM as "member" of PI team)
Extra reviews (ITA, Code500)	Bring them on!	Same as above: Utilized Explorers office resources, experiences, and connections, as an asset for the PI-PM team to contain review and RFA proliferation

Main takeaways.

It is not if there will be crises, but how you will deal with them when they appear. Buy down risk early, when you still can.

“It is not the strongest of the species that survive, not the most intelligent, but the one most responsive to change.” – Charles Darwin

People are the most valuable asset in a program, their management is more important than that of technical resources.

"Project plans are easy if people were not involved” – Unknown